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The CHASMS conceptual model of cascading disasters and social vulnerability: The COVID-19 case example

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ABSTRACT

Complex environmental, economic, and social conditions in the places we live provide strong cues to our longevity, livelihood, and well-being. Although often distinct and evolving relatively independently, health disparity, social vulnerability and environmental justice research and practice intertwine and inform one another. Together, they increasingly provide evidence of how social processes intensify disasters almost predictably giving rise to inequitable disruptions and consequences. The domino and cumulative effects of cascading disasters invariably reveal inequities through differential impacts and recovery opportunities across communities and subgroups of people. Not only do cascading disasters reveal and produce inequitable effects, the cascade itself can emerge out of compounded nested social structures. Drawing on, and integrating, theory and practice from social vulnerability, health inequity, and environmental justice, this paper presents a comprehensive conceptual model of cascading disasters that offers a people-centric lens. The CHASMS conceptual model (**C**ascading **H**azards to dis**A**sters that are **S**ocially constructed e**M**erging out of **S**ocial Vulnerability) interrogates the tension between local communities and the larger structural forces that produce social inequities at multiple levels, capturing how those inequities lead to cascading disasters. We apply the model to COVID-19 as an illustration of how underlying inequities give rise to foreseeable inequitable outcomes, emphasizing the U.S. experience. We offer Kenya and Puerto Rico as examples of cumulative effects and possible cascades when responding to other events in the shadow of COVID-19.

COVID-19 has vividly exposed the dynamic, complex, and intense relevance of placing social conditions and structures at the forefront of cascading disaster inquiry and practice. The intensity of social disruption and the continuation of the pandemic will, no doubt, perpetuate and magnify chasms of injustice.

1. Introduction

Complex environmental, economic, and social conditions in the places we live provide strong cues to our longevity, livelihood, and well-being. For instance, life expectancy varies dramatically by country, as short as 60 years of age in some countries and over 80 in others [1], and even by locality with as much as a 20-year gap between U.S. counties [2,3]. In the U.S., data reveal that a person's zip code has significant bearing on how long one will live, and the opportunities, or lack thereof, for upward mobility [4]. In a parallel though distinct pathway, environmental justice research focuses on the ways in which social position produces differential environmental burdens and injustices [5,6], aligning with hazard/disaster risk research that consistently reveals disadvantaged populations bear the burden of higher environmental risks and slower recovery from disasters. The constellation of the root causes of health inequities [7,8] are the same fundamental forces that give rise to social vulnerability to disasters [9,10], exacerbating the effects of natural and technological disruptions. Although often distinct and evolving relatively independently, these fields of research and practice (health disparity, social vulnerability and environmental justice) intertwine and inform one another. Together, they increasingly provide evidence of how social processes intensify disasters almost predictably giving rise to inequitable disruptions and consequences.

Scholars have used a variety of terms to describe hazard events that interact, lead to other events, and result in multiple interrelated disasters. Na-tech disasters [11], double exposure [12], hazard

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interactions [13], and compound hazards (events) [14], all inform emerging work in cascading disasters. Pescaroli and Alexander [15,16] provide an early definition of a cascade as a disaster that gives rise to subsequent crises, using the 2011 Tōhoku earthquake in Japan and the subsequent Fukushima Dai-ichi nuclear power plant failure as a primary example. Cascades are also affected by their context and pre-existing vulnerability could mitigate or fuel the progression of cascades [16]. Unlike the primary event which emerges out of natural systems, secondary crises are causally related to the primary disaster and are often more directly linked with human activities including built environment, structures, institutions, and emergency management activities [17]. Studies of cascading disasters have increasingly focused on the vulnerability of critical infrastructure as a major trigger of cascading effects [15,18]. A cascading disaster may extend beyond Pescaroli and Alexander's [15,16] description to include multiple unrelated disasters striking the same area in close succession prior to recovery, or even simultaneously as response to one is still underway. Suffering is further compounded by interactions among unrelated disaster events. Although the chain of these disaster events is not causally related, human systems are stressed, accumulating and amplifying social vulnerability and inequities, further impeding the recovery. Emerging research on cascading disasters must incorporate concepts from social vulnerability and inequities to comprehensively evaluate, respond and mitigate the cascade.

Regardless of specific definitions or approaches, the domino and cumulative effects of cascading disasters invariably reveal inequities through differential impacts and recovery opportunities across communities and subgroups of people. A tendency toward more traditional apolitical and technical approaches, which are dominant in the physical science and engineering-based hazard risk reduction community, minimizes considerations of social conditions and power relations [19]. The social vulnerability paradigm embeds people within broader social systems that produce opportunities or constraints for individual agency decision-making. Individuals/households/communities organize and adapt within broader structural contexts. Alongside understanding and addressing how people and communities adapt to disasters and risks, the root causes of marginalization that emerge from unequal power relations cannot be ignored [20] and are extraordinarily challenging to confront and solve. In fact, many reasons for increasingly common cascading disasters are grounded in social systems, including: (1) global phenomena, such as globalization, urbanization, and climate change, and (2) socioeconomic risks including aging societies, economic inequality, unplanned and disjointed development, and unequal access to education and healthcare systems [21].

The pre-existing forces that produce health inequities, social vulnerability to disasters, and environmental injustice underpin the production of cascading disasters. With each ensuing insult (natural or human-induced) that results from cascading events, social, economic, and political inequities are revealed and intensified. In turn, these manifest in even more severe health inequalities and expose challenges for vulnerable and marginalized groups both in the short- and long-term. Not only do cascading disasters reveal and produce inequitable effects, the cascade itself can emerge out of compounded nested social structures. Drawing on, and integrating, theory and practice from social vulnerability, health inequity, and environmental justice, this paper presents a comprehensive conceptual model of cascading disasters that offers a people-centric lens, challenging technocentric traditions. The CHASMS conceptual model (**C**ascading **H**azards to dis**A**sters that are **S**ocially constructed e**M**erging out of **S**ocial Vulnerability) interrogates the tension between local communities and the larger structural forces that produce social inequities at multiple levels, capturing how those inequities lead to cascading disasters. We apply the model to COVID-19 as an illustration of how underlying inequities give rise to predictable inequitable outcomes, emphasizing the U.S. experience. We offer Kenya and Puerto Rico as examples of cumulative effects and possible cascades when responding to other events in the shadow of COVID-19.

2. Background: social vulnerability, health inequity, and environmental justice underpinnings of cascading disasters

Health inequity, social vulnerability, and environmental justice emanate from parallel streams of inquiry. While perhaps not informing one another as frequently as they could, all denote how placed-based socioeconomic conditions and larger social structural forces produce inequities that manifest in differential health and/or disaster outcomes. Local community decision-making, like individual agency, is constrained and influenced by these larger forces. Progressing towards equity and reducing risk for all necessitates changing these systems along with facilitating adaptation and resilience at the local, household, and individual levels. When cascading events occur, inequity (unfair, avoidable differences) worsens. Poor governance is magnified, corruption or cultural exclusion intensifies, and the already uneven distribution of health or health resources is further amplified. Each ensuing insult continues to expose inequities in predictable ways when social inequities are not rectified. When subsequent events occur prior to recovery, inequities become intensified and effects compound producing cascading impacts. In this way, cascading disasters emerge out of inequities and social vulnerability similar to a series of domino failures in critical infrastructure triggered by a natural event.

2.1. Social vulnerability (to disasters)

Experiences with hazard events are a part of human lives since we are all part of, and depend on, the natural environment. Still, an environmental threat does not translate directly into a disaster. The transformation of a hazard event into a disaster emerges at the intersection of human and physical forces [22,23]. Disconnects between human, physical and built systems when hazard events occur reveal pervasive social troubles that inherently make response and recovery intensely more challenging [24]. While knowledge produced in the physical and ecological sciences along with engineering is essential, reducing disaster risk requires taking social systems into account moving beyond technological/engineered fixes and behavioral approaches to reducing risk [25].

The severity and consequences of hazard events vary within and across communities, regions, and countries because of the social conditions that exist in these places over time [9]. Further, subgroups of people within the same geographic area consistently experience higher loss of life, displacement, and longer recovery periods from disasters because of persistent social forces that produce inequities [26]. Social vulnerability emphasizes how social, economic, and political interactions intensify or lessen disaster impacts and how place inequities intensify burdens on particular communities [27]. Importantly, beyond capturing differential burdens that invariably occur in the aftermath of disasters and during recovery (outcomes), social vulnerability engages with underlying social processes deeply rooted in historical events and social structures that produce inequities and perpetuate social disparities.

Stemming from the ways society stigmatizes, marginalizes, and perpetuates inequalities, social vulnerability is well documented for many groups, including but not limited to, income [28–30], class, race or ethnicity [31,32], gender [33], age [34,35], health [36], language [37], or immigration status [38,39]. Commonly, social vulnerability is not about only one social characteristic of a group, but rather a combination or intersection [40] that often intensify disenfranchisement or marginalization. These groups are not socially vulnerable because of their virtues, rather societal structures place them in harm's way across all disaster management phases. Social stratification and inequalities manifest in quality and availability of numerous resources, such as healthcare or emergency response services [41].

Social vulnerability invariably interconnects with resilience and much of literature and practice has adopted this term in place of social vulnerability, possibly because of a more positive connotation and to

deter from labeling groups in negative ways, both of which are creditable reasons for shifting terminology. Resilience, like social vulnerability, does not have a singular definition, approach, or agreed upon set of metrics [42]. Certainly, a socially vulnerable group or community can be resilient; they are not simply victims. If they "rebound," used in some definitions [43], and recover to a pre-disaster state with income disparity, inadequate housing, or food insecurity, vulnerabilities are not reduced. Moving beyond rebounding, Norris et al. [44] present a definition of community resilience as "a process linking a set of networked adaptive capacities to a positive trajectory of functioning and adaptation in constituent populations after a disturbance." Their interpretation moves beyond "rebounding" and offers a robust approach grounded in social-psychology, but does not directly capture the larger structural forces so foundational to social vulnerability that produce barriers to rebounding and improving living conditions to reduce risk to future disasters. In fact, they acknowledge the need for further explorations in social vulnerability and resilience.

This paper contends that the concepts of resilience and social vulnerability complement one another. Further, resilience can deflect attention away from enduring vulnerabilities and the exhaustion of resilience in the face of multiple or cascading disasters. For example, places like Haiti are so beaten down over a long period that survival may perhaps be a more accurate descriptor than resilience. Haiti has suffered from entrenched poverty, lack of investment in public infrastructure and political upheaval for many decades. When an earthquake struck in 2010, the estimated 46,190 -111,794 deaths and over a million homeless resulted as much from the diminished social and built conditions than from the 7.0 magnitude of the event [45]. Several major hospitals were destroyed limiting trauma care and lack of sanitation and potable water systems contributed to a subsequent outbreak of cholera [46]. Still suffering from the earthquake, Hurricane Sandy ravaged the island in 2012 leaving the island nation once again devastated. Focusing on social vulnerability is not about highlighting inadequacies, but rather emphasizing enduring marginalization and disenfranchisement. Social vulnerability explicitly underscores the structural underpinnings of inequity as it interplays with community agency; it emphasizes deeply rooted inequities that produce injustices.

2.2. Health inequity

Health inequities have direct parallels to social vulnerability. Health inequity refers to systemic differences in health outcomes attributable to social and economic conditions [47]. The terms health inequality and inequity are sometimes used interchangeably, but have distinct meanings. Resnik and Roman [48] distinguish health inequity from health inequality based on whether social justice is a factor. In other words, an inequity exists if the differences in the health outcomes are attributable to disadvantages emerging from the social system. According to CSDH [7,7], the social conditions and contexts in which people live, work, age, and die – the social determinants of health – are largely constructed and perpetuated by political, social, and economic forces. Opportunities for leading a healthy life are regulated by macro- and micro-level forces at different levels (distribution of power, income, goods, and services) that produce inequitable access to healthcare and education, housing, work and leisure [47], and as a consequence, poor health concentrates among the socially disadvantaged [49]. Health inequities emerge from unequal distribution of power, income, goods, and services, which in turn affect the access, availability and quality of healthcare, education, and other living conditions at a more local level [47,50]. Social determinants also constrain individual behaviors or lifestyles that support or undermine health. Addressing the social determinants of health fundamentally leads to health equity.

Even though social vulnerability and health inequities models identify the same social forces, the social determinants of health framing are infrequently applied to disaster research or integrated into discussions of social vulnerability. Public health departments identify health risks from extreme weather events; however, the inequitable distribution of these risks among population groups is rarely discussed [51]. Research on heat disasters is one notable exception that incorporates the social determinants of health with constructs of social vulnerability [52–54]. Importantly, there is a limited understanding of the impacts of disasters on populations in medically underserved communities. By extension, disaster response and recovery rarely addresses healthcare disparities or those with chronic diseases [55].

2.3. Environmental justice

Health inequity and social vulnerability give rise to intense environmental injustices when disasters perpetually disproportionately affect disadvantaged communities [31]. A combination of civil rights and environmental protection, environmental justice is defined as "the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income, with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies" [56]. If environmental justice is realized all people should have equitable protection from environmental hazards and equal access to decision-making in their communities [57]. In the U.S., the environmental justice movement emerged out of the Civil Rights Movement and subsequent studies that documented low income, African American communities were much more likely to be located near toxic waste dumps across the entire U.S [58–60]. The concept of environmental injustice at the international level is associated more with poverty than race and is utilized as a guiding principle for alleviating the link between poverty and environmental degradation, which are the consequences of market and public policy failures [61]. As an example, globally, developed countries have long exported hazardous wastes to developing countries seeking cheap options for disposal, which causes disproportionate environmental health burdens on the waste importing countries [62].

Disaster studies using a social vulnerability lens consistently show intense environmental injustices. Thus, it is likely that cascading disasters even more acutely and intensely reveal and exacerbate inequities. Community vulnerabilities and social inequities that predate the initial disaster are exposed over time again and again with each ensuing event. Since the exploration of cascading disasters is relatively new, incorporating, documenting, and assessing how marginalized groups suffer, cope, and adapt is essential for achieving environmental justice and ensuring all communities are equitably protected and included in the part of mitigation and adaptation strategies.

2.4. Conceptual model

Extending the social vulnerability paradigm, whereby disasters are considered socially constructed phenomena requiring systemic social solutions, the CHASMS conceptual model (**C**ascading **H**azards to dis**A**sters that are **S**ocially constructed e**M**erging out of **S**ocial Vulnerability) presented in this paper (Fig. 1) emphasizes the role of social systems in the generation of a cascade, drawing on elements from several existing models in health and vulnerability. The CHASMS model contends that cascading disasters are entrenched in the power structures that create inequities and the cascade emerges out of social, political, cultural, and economic systems that shape community and individual risk at multiple temporal and spatial scales. The conceptual model is place-based with local communities nested within multiple micro and macro levels of complex interactions, and foundationally embedded within nature, not apart from it. As such, the outer most layer, or foundation of the model, is the Earth's physical systems and processes upon which all else relies. Health inequity (HI) and social vulnerability (SV) reside at the core of the CHASMS model, which fundamentally produce extreme environmental (health) injustices (EHI) across populations. Conversely, reducing social vulnerability and achieving health equity minimize environmental injustices that result from cascading

Fig. 1. CHASMS Conceptual Model of cascading disasters, social vulnerability (SV), health inequity (HI), and environmental injustice (EHI).

disasters.

The CHASMS model takes a community or population health perspective and places local community at the center nested in higher level structural forces. The Socio-Ecological Model of health is commonly applied across public health [63] and offers several components to the CHASMS model. The Socio-Ecological Model of health is a framework for understanding how complex micro and macro forces influence individual health outcomes and health behaviors. In turn, these behaviors also influence social (and physical) environments [64,65]. A person's behavior is not just about individual characteristics or abilities. Rather, reducing risky health behaviors necessitates addressing macro level influences that form strong influences and create social environments that encourage particular behaviors. For example, limiting the availability of tobacco products through policies, such as increased taxes (cost), along with smoking cessation education and programs reduces overall smoking rates. As one parallel in disaster risk reduction, efforts to increase preparedness target changing norms in communities along with guidance geared towards the individual or household. The nested levels of complex interactions between agency (an individual's ability to independently make change) and context provides an avenue for risk reduction. However, while highlighting the environment-individual tension in the formation of behavior, the Socio-Ecological Model does not typically challenge larger structural forces (e.g. racism, classism, entrenched poverty, etc.) that shape opportunities and produce constraints to individual or even community agency.

The next layer outside of community-level health inequities and social vulnerability at the center of CHASMS includes a set of community capitals that help understand how people, households, and communities adapt to the structural pressures within which they exist. This layer is derived from the livelihood approach that has been commonly applied in development studies to capture complex strategies household members use to meet basic needs [66,67]. Sustainability is achieved if the household can meet its basic needs and can withstand and recover from a disruption. While much of the applications in development studies are at the household level, the CHASMS model emphasizes the resources at the community level following the Community Capitals Framework in community development [68]. The intertwining types of capital include financial (monetary resources), human (education, knowledge, skills, leadership), natural (quantity and quality of physical environment), physical (built infrastructure), social (networks, groups, organizations), cultural (values, norms and beliefs), and political (influence of policy, rules, laws, regulation). This framing offers a way to examine community wellbeing from a systems perspective. The role of social capital in reducing vulnerability is explored in the disaster literature to understand the relationships that increase resilience [69,70]. In a parallel fashion, social determinants of health research identify strengthening social capital in communities as a pathway to reducing health disparities [71]. In both cases, wellbeing is not only about financial wealth, but also includes a wide array of social arrangements of capitals that are dynamic and interrelated. The livelihood approach is fundamentally bottom-up, emphasizing adaptation to larger structural forces. However, the larger structural forces in early applications were relegated as contextual, acknowledging policies could reduce vulnerability, but frequently not capturing or explicitly addressing these higher-level powers that inevitably reinforce inequities or provide avenues for change at the community level.

Streams of research addresses this shortcoming [66], including Wisner et al.'s Pressure and Release Model [10], which emphasizes the power structures that drive the root causes of disasters. The Pressure and

Release (PAR) model informs CHASMS in fundamental ways, most notably by grounding it in the root causes of health and disaster inequity (social vulnerability) that give rise to the intensity of the disaster. On one side of the model, root causes, or underlying conditions that emerge from wealth, power and resource distribution, create dynamic pressures that result in unsafe conditions. The natural hazard presses in from the other direction towards the unsafe conditions, producing the crisis at the pressure point between the natural event and unsafe conditions. The PAR model explicitly emphasizes social forces as drivers of disasters rather than behavioral decision-making.

The dashed line in between each layer in CHASMS represents complex interactions between agency at the most inner circles and each level of contextual power structures that surround and influence all community risk reduction activities. The tension between the strength of the layers (black arrows pushing in on the hazard event) counteract forces from the hazard(s) that impinge (red arrows pushing from the event toward the social systems), mirroring the pressure point from the PAR. The progression of vulnerability crushes down onto a local community generating the disaster or catastrophe. In CHASMS, the extent that the fissure pushes into each layer creates a chasm, stemming from the inability of the social systems to "push back" on the event. The local community experiences the most intense effect.

Fig. 2 illustrates a cascade when events related to one another domino in close succession or when two or more separate events occur in a close enough time period that recovery was not fully realized. The first event (event/time 1) courses through the contextual conditions at each layer slamming onto the local community where effects are felt most acutely and inequities (EHI-SV-HI) exacerbated. Before recovery is possible, subsequent events (event/time 2 and 3) further intensify destruction, producing a larger fissure with each ensuing insult. Each disaster wave makes recovery more challenging. The emphasis on social vulnerability intentionally means that recovering entirely and returning to "normal" does not necessarily minimize vulnerability. For example, if a community had high unemployment, low food security, and poor housing prior to an event, returning to those conditions does not reduce social vulnerability or minimize risk to the next disruption. Adaptation might even occur, strengthening the community, but the underlying inequities perpetuate susceptibility to disasters.

Much like the Socio-ecological Model of Health, the model interrogates the degree to which structural forces interact with community (individual) agency. Local to global inequities (power, economic, social, environmental), human rights violations, globalization, warfare, and especially climate change, all further intensify future and potential risk for cascading disasters. The CHASMS model moves beyond simply acknowledging larger forces to calling for change at multiple levels to decrease vulnerability and increase equity.

2.5. COVID-19 case example

While COVID-19 is somewhat unique in its global extent as compared to other natural events, infectious diseases are consistently classified as a natural hazard under a biological classification [72,73]. For infectious diseases, organizational response emerges out of public health preparedness that aligns with emergency management functions. In fact, many similarities exist between this global pandemic and other catastrophic events, such as risk communication in the time of uncertainty, challenges with data-driven decision-making, failures and successes in policy and leadership, or trust in and communication of science. Repeatedly, major natural catastrophes seemingly take communities by surprise, even though experts have run scenarios, conducted table-top exercises, or conceived the possibility of catastrophic events [74].

COVID-19, which is the disease caused by the newly identified coronavirus, emerged in Wuhan City, China in December, 2019 [75,76] and quickly spread to other countries. The World Health Organization declared a global pandemic on March 11, 2020. The pandemic continues to grow with increasing numbers of confirmed cases and deaths occurring in almost if not all countries around the world [77]. While its rapid emergence caught society by surprise, the scientific community had warned of the impending threat from an emerging infectious disease for years and even decades, particularly with 2003 SARS outbreak (a coronavirus) and the 2009 H1N1 influenza pandemic as forewarnings of the risk for an infectious disease global pandemic [78–80]. The predictable ways that the disease has disproportionately affected socially vulnerable populations is of particular relevance for this paper, emphasizing the continued need to incorporate a vulnerability paradigm into the study of cascading disasters. Further, pandemics like COVID-19 offer evidence of cascading events that have unrelated triggers, but which occur at the same time overburdening response and recovery capabilities.

2.6. Cascade: cumulative effects, chronic underlying conditions, and social vulnerability

Over and over as the COVID-19 pandemic has unfolded, systemic power, economic, political and social inequities (the outer layers of CHASMS) that give rise to social vulnerability and health inequity (HI, SV at the center of CHASMS) reveal themselves. While infectious diseases are often described as "equal opportunity" for making people sick, this is not, in reality, a truth any more than a hurricane or an earthquake equally wreaks havoc across geographic areas or population subgroups. In fact, all people do not experience a hurricane's force in the same way; Hurricane Katrina did not "seek out" low income, African American communities who were disproportionately affected. The numerous instances of COVID-19 excessively affecting marginalized populations

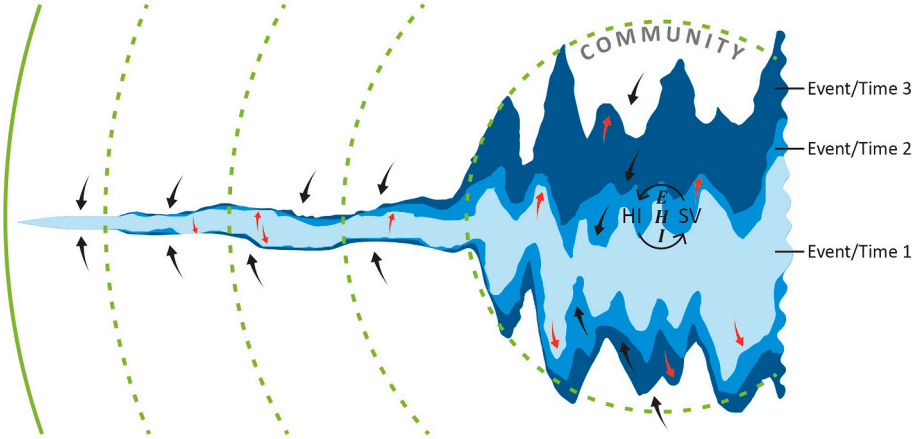

Fig. 2. The cascade fissure in the CHASMS Conceptual Model.

should hardly be surprising given longstanding evidence of how this unfolds disaster after disaster. Higher rates of disaster-related morbidity and mortality for marginalized groups are rarely about individual or group characteristics (center of CHASMS). Rather, they stem from inequities rooted in social and economic systems (outer layers of CHASMS) that lead to people and communities having differing options for protecting themselves, varied opportunities for seeking and obtaining quality healthcare, and generally fewer resources across a set of dimensions. This section documents some examples of how these inequities have manifested during the COVID-19 pandemic, emphasizing the U.S., although emerging evidence suggests similar patterns globally with variations in burdens depending on context.

Higher rates of disease and death from COVID-19 are consistently documented across nearly every group typically described within the vulnerability to disasters literature and typically arise out of injustices that permeate society. Importantly, susceptibility is rarely about a singular condition or situation, but rather an intersection of individual and societal factors. Access to high quality healthcare, safe environments, and education; food, water, housing, and economic security; and freedom from racism, discrimination, and gender bias, all reduce the risk of perishing and suffering from natural disasters, including infectious diseases/COVID-19. For example, socially vulnerable neighborhoods in the south and west side of Chicago, with high percentages of people with less than high school educations, low median incomes, high unemployment, and high rates of obesity, were at higher risk for contracting COVID-19. These areas also had higher concentrations of African Americans. The structural factors of racism and discrimination that led to high social vulnerability in these neighborhoods predated the COVID-19 epidemic [81]. The statistical descriptions touch on the intersectionality of conditions and larger forces at play that produce the inequities.

As with most respiratory diseases, such as influenza or pneumonia, elderly adults and those with underlying chronic health conditions have a higher risk of contracting and dying from COVID-19 [75,82–84]. Elderly people living in nursing homes and assisted living facilities represent a significant proportion of deaths in the U.S., stemming from high concentrations of people with underlying conditions living in close proximity [85]. As of May 31, 2020, one-third of confirmed COVID-19 Medicare and Medicaid (U.S. federally registered) nursing home resident cases died (32,000 people) [86]. This does not represent other types of nursing homes and assisted living facilities, nor does it include health workers in these facilities. As such, this is likely an undercount of deaths in nursing homes. Still, approximately one-third of all deaths in the U.S. at the same point in time are attributable to nursing home settings.

Frontline healthcare workers are at high-risk for COVID-19 infection. Wearing personal protective equipment (PPE) in conjunction with infection prevention and control measures in the workplace are necessary for reducing this risk in care settings. The 2009 H1N1 influenza prompted additional attention towards PPE and a report from the Institute of Medicine even noted that “keeping the research momentum going is critical, because between pandemics the focus of research efforts often moves to other issues and the nation remains underprepared” [87]. Yet, in 2020 the reuse or limited availability of PPE increased the risk of acquiring COVID-19 [88]. CDC [89] has documented 72,346 COVID-19 cases among healthcare workers with 383 of them dying as of June 10, 2020. These data likely underrepresent the healthcare worker burden since only 21% of the data from which the numbers were generated included the information about patients’ occupations as healthcare workers.

Systemic racism, lack of access to high quality healthcare, economic disparity and persistent poverty combine to produce extreme health inequities, which unsurprisingly have occurred during COVID-19. The rate of infections and related deaths are disproportionately higher for African Americans [90,91]. While 23% of people who have died from COVID-19 were African Americans [92], they make up only 13% of entire U.S. population [93] and so African Americans have a death rate two times whites. Hispanic/Latino populations, particularly non-white, also experience higher COVID-19 rates [94], interfacing with age, occupation, and immigration status.

Indigenous populations, refugees, and immigrants are also vulnerable. Indigenous populations are historically underserved due to language and cultural differences, structural inequity, racism, and discrimination [95]. They have limited access to preventative measures and healthcare systems, which further accelerated the spread of COVID-19 in indigenous communities in Australia, Brazil, Canada, and the U.S [95–97]. COVID-19 cases per capita in Navajo Nation in the Southwest U.S. outnumbered those in New York and New Jersey, which are marked by the highest per capita infections in the U.S [98]. Refugees are also at a higher risk of COVID-19 because globally they tend to live in refugee camps with multiple people in limited spaces, while grappling with malnutrition and limited access to the quality healthcare system at the same time [99].

People living in crowded or densely populated conditions, such as prisons, nursing homes (already described), dormitories, and schools, have a higher risk of contracting COVID-19. For example, the crowding in prisons hampers social distancing and daily changes of shifts of correctional officers and staff coming and going increase prisoners’ exposure to COVID-19 [100]. Further, 40% of prisoners and jail inmates in the U.S. have chronic medical conditions, a higher rate than the general population [101], keeping in mind that the U.S. has the highest rate of incarceration of any country in the world [102], a statistic only revealing the tip of an system fraught with injustices (i.e. 40% of prison population in the U.S. is Black). As of June 4, 2020, 40,656 COVID-19 cases were reported in state and federal prisons in the U.S [103].

For many segments of the population, adhering to stay-at-home orders and physical distancing are luxuries. Social-distancing strategies, such as telecommuting or avoidance of public transit, or having a safe home space may not be realistic options for at-risk populations. During COVID-19, many low-paying jobs were considered essential even as people were asked to work at home and schools moved online. Bus drivers, grocery store workers, and people processing the delivering goods to homes, all relatively low wage positions, suddenly became vital, increasing their exposures. Workers in these occupations are predominately people of color. In contrast, except for medical professions, top income earners, such as lawyers, engineers, or software developers [104], could more easily work from home or reduce their visits to workplaces without bearing the risk of reduced income or job loss. Some segments of the labor force lend themselves to telecommuting, while others do not. People and students with technology and high-speed Internet can more easily work/study from home, assuming they can afford these resources and that high-speed Internet even exists. This is unfortunately not the case for millions of people across the U.S. The digital divide in the U.S. and globally has never been more apparent than during COVID-19.

Many people do not have safe homes to shelter in-place. Even prior to the COVID-19 pandemic, a staggering 30% of women and girls (15–49) globally have suffered from intimate partner violence in their lifetimes [105] and in the U.S. about one in four women and nearly one in ten men have experienced intimate partner violence [106]. In the U.S., at least one in seven children are abused and/or neglected [107] and 1770 died in 2018 [108]. Fear and uncertainty, isolation, economic tensions from job loss, and psychological stressors create the “perfect storm” for increases in domestic violence during COVID-19 [109]. Homeless people are at a higher risk because they are likely to be older adults, have underlying medical condition, sleep in group settings when utilizing shelters, and do not have access to consistent nutrition and hand-washing [82,83,110]. Best responses for reduced transmission of COVID-19 intensify vulnerability for many, putting them directly in harm’s way from a different pandemic.

While this section does not capture every manifestation of social vulnerability from the COVID-19 pandemic or explore the underlying conditions deeply, it illustrates the multifaceted ways that health

inequity and social vulnerability give rise to environmental injustice. These illustrations only touch the surface of cascades in social vulnerability during COVID-19. We must engage with the dynamic nature of social vulnerability across numerous other human conditions as the pandemic continues and after it has passed, including, but not limited to, disparities in unemployment from the ensuing economic recession; mental health issues; gender inequalities; lack of safe, adequate, and affordable housing; disproportionate effects on education at all levels; and the brutal police killings of Black people in the U.S. stemming from deep structural racism and ensuing protests throughout cities across the U.S. The cascade does not stop, as other natural events have, and will, unfold in the context of COVID-19.

2.7. Cascade: disasters in the context of COVID-19

Even as the COVID-19 pandemic has progressed, numerous other significant disasters have occurred stretching response capacities due to compounded demands. Concurrently dealing with COVID-19 response and other natural disasters poses significant challenges in resources and balancing approaches. Since January 1, 2020, EM-DAT has recorded 88 natural disasters in 56 countries [111],[1] mirroring the experiences of hazard prone areas that experience a multitude of large-scale hazards within the short period of time. Some might consider this compounding events, but given the stresses on social, economic and political systems that never have an opportunity to recover, the cascade may occur in downward spiraling social vulnerability. Kenya (flooding, COVID-19 and cholera) and Puerto Rico (hurricanes, Zika, earthquakes, and COVID-19) offer illustrations.

Kenya has experienced exceptional challenges due to multiple disasters compounded by preexisting social and economic disadvantages, consequent health inequity, and environmental injustice. Despite the country's rapid economic growth in the last two decades, 36.8% of Kenyan population lives under the international poverty line of US$1.90 per day [112]. Access to quality healthcare is tenuous and health outcomes are far below global averages. The poor tend to visit medical or healthcare facilities approximately 30% less than the rest of population and the mean distance from a health facility is about 60% farther for low income groups as compared to high income groups [112]. Stark differences are also found between rural and urban areas in Kenya. Layered on these conditions, Kenya recently experienced massive flooding in late April of 2020 in the midst of the COVID-19 pandemic. The flood affected 75% of counties across Kenya, killed 194 people and displaced approximately 116,000 people to temporary camps, with more than 70% lacking access to clean water [113,114]. The flood and evacuation sheltering raised the risk of diseases and debilitated efforts to control COVID-19 transmission [114]. As if the flooding was not enough, a cholera outbreak followed the flood [115] and the flood also halted the control of "worst locust crisis in decades" [116], which could decrease food insecurity. Not only are response efforts hindered by the numerous events, social vulnerability and health inequities only intensify with each ensuing peril.

Puerto Rico has also experienced compounded series of events without substantial respite in almost five years, starting with an outbreak of Zika virus in 2016, Hurricane Maria in 2017, earthquakes in 2019/2020, and now COVID-19. These events are superimposed on extreme social inequities. In Puerto Rico, GDP per capita is about 50% less than in the U.S. to which it is a territory [117] and 4 out of 10 people live in poverty [118]. The Puerto Rican healthcare system receives less funding from the U.S. government than the mainland, and the lack of federal funding support accelerates the decline in the quality and availability of healthcare facilities in Puerto Rico [119,120]. Zika remains with eight new cases of symptomatic Zika virus in 2020 [121], requiring continual monitoring and attention. In January 2020, when a 6.4 magnitude earthquake shook the island displacing more than 7500 people [122], the island was still recovering from Hurricane Maria [123, 124]. In the wake of COVID-19, Puerto Rico implemented strict lockdown orders and social distancing even while some people who were forced out of their home during the earthquake were still living in tents [125]. Puerto Rico continues to rebuild and recover as it faces COVID-19 and just as with Hurricane Maria relief, government support still lags behind the rest of U.S., and so Puerto Rico has the lowest COVID-19 testing rates per capita in the U.S [119].

Puerto Rico and Kenya represent the numerous places across the globe that are facing other disasters in the context of COVID-19, stressing already stressed socio-economic systems. Conditions of compounding social vulnerability reduce capabilities to withstand any further hazard events that occur in the foreseeable future. Both of these experiences foretell what could unfold as communities prepare for upcoming wildfire, hurricane and/or influenza seasons in the context of COVID-19 [123].

2.8. Interrupting the cascade

The CHASMS model requires intervention at multiple levels to reduce social vulnerability and strengthen resilience in the face of COVID-19 (and subsequent pandemics) to interrupt cascades. Early detection and response that is consistently applied is foundational to the containment of pandemics [126,127]. Early detection and response rely on sensitive, active surveillance, testing, and reporting at every level, including individuals, households, communities, workplaces, hospitals, and national and international agencies. However, simply identifying cases is not enough. Collecting data and information on vulnerable populations is also essential (along the dimensions of the capitals described in the model above). This includes, but is not limited to, age, access to health care, occupation/workplace, race/ethnicity. Without collecting these data as part of reporting and surveillance systems, capturing differential impacts is impossible and systematically targeting response and relief efforts will fall short. Strengthening testing and reporting systems now can mean more quickly containing a second wave, minimizing differential impact with less disruption to the economy and providing time for vaccine development. For example, early detection spared the U.S. from a flu epidemic in 1957 [128,129].

At the institutional level, building stocks of personal protective equipment for healthcare personnel, ventilators, and necessary medications, along with maintaining rosters of healthcare workers who are cross-trained and willing to step in as needed in hospitals and in skilled nursing facilities, all minimize disruptions, reduce exposure to essential workers, and enable shifting resources to different areas informed by the reporting data. Ensuring all people have access to basic health care and moving beyond identification of communities with health care gaps to target basic care for treatment of chronic conditions will ensure an equitable response, ultimately protecting all. Efforts to offset lost wages resulting from unemployment, quarantine, illness, and/or death also reduce the intensification of social vulnerability. Investing in public health systems at the same level as hospital and medical care improves population health. All of this is achievable with current knowledge and resources, but takes political and social will so that we do not perpetually repeat the same intensification of disaster events because of inequitable social systems.

The COVID-19 pandemic highlights the need for, and importance of, coordinated efforts by leadership within and between all levels from the local to the global. Preparedness, response, and recovery should be guided by best-practices and science-informed decision-making, ultimately saving lives. Risk communication in the U.S. stands out as one example of misalignment during the current pandemic. Policy makers and political leaders have delivered widely differing information about

[1] The initial criteria for EM-DAT disaster entry is a disaster event that caused 10 or more deaths, affected 100 or more people, or led to the declaration of emergency requesting for upper level government or international assistance [131].

transmission, prevention, and potential treatments, often without scientific foundation. These conflicting messages interface with the level of trust people have in scientific knowledge and evidence-based decision-making. In fact, the mistrust of science is embedded within decades of efforts by many institutions and organizations to undermine confidence in scientific information on public health issues in the U.S., including smoking and climate changes [130]. In situations of national emergency, clear, consistent messaging based in the best science is critical for implementing a systems-based approach to coordinate response and mitigation efforts.

Attending to larger entrenched structural inequities is much more complex and requires multifaceted and transformational solutions at the intersection of siloed sectors. The COVID-19 pandemic once again underscores an imperative to undertake change that explicitly reduces inequities at the core, creating the structures and policies that give people and communities the ability to create solutions at the community level. The more that everyone has their basic needs met and public infrastructure and support systems are functioning, the more we can focus on handling the unforeseeable complications that arise when disruptions and disasters occur and prevent them from cascading.

3. Conclusion

The CHASMS conceptual model presented in this paper places social structures and conditions at the forefront of cascading disasters. Health inequity and social vulnerability give rise to extreme environmental injustices and CHASMS calls for change at multiple levels to decrease vulnerability and increase equity. The model offers a comprehensive framework that is explicitly people-centric avoiding a tendency towards predominate technocentric solutions. COVID-19 has vividly exposed the dynamic, complex, and intense relevance of placing social conditions and structures at the forefront of cascading disaster inquiry and practice. The intensity of social disruption and the continuation of the pandemic will, no doubt, perpetuate and magnify chasms of injustice. While the virus emerged from natural systems, the far-reaching effects are a direct result of failures in social systems. Inquiry must continue to uncover and illuminate the multi-faceted ways that society could have reduced the extent of the COVID-19 pandemic with subsequent scientifically informed action to reduce risk for the next emerging infectious disease.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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